Fermilab

Fermi National Accelerator Laboratory
P.O. Box 500 • Batavia, Illinois • 60510

TD-01-067
September 28, 2001

Finite Element Magnetic Analysis of the Cornell Three-Pole Wiggler Model

S. Yadav
Fermi National Accelerator Laboratory
MS 316, PO Box 500, Batavia, IL, USA

Abstract*—A 2-dimensional finite element magnetic analysis of a longitudinal cross-section of a three-pole wiggler model (designed by A. Mikhailichenko at Cornell and built by the Laboratory of Nuclear Studies at Cornell) has been performed. One of the main purposes of this analysis was to obtain the Lorentz force distribution in the coils; which would be transferred to a separate mechanical model to perform the mechanical stress analysis of the wiggler model during cool-down and excitation.*

Summary

Figure 1 shows a schematic of the Cornell's three-pole wiggler model [1], whereas Figure 2 shows a photograph of the model. We have performed a magnetic analysis of this three-pole model to extract the Lorentz forces acting on the coils, which we require for performing a mechanical analysis. We used the magnetic properties of 1010 steel in our analysis. Figure 3 provides the BH data for this steel in a tabular format, while the same data is plotted in Figure 4. The area representation of the finite element model used is shown in Figure 5. We discretized the model using 4-noded PLANE13 elements. Each half of the coil is divided into 9 x 8 finite elements. The current excitation in the coils is provided below:

1. CENTRAL COIL:
   Total Number of turns = 675
   Current = 675 x 170 A = 114.75 kA
   Coil Dimension = 0.8285" x 0.75"
   Current Density = 2.862 x 10^8 A/m^2

2. END COILS:
   Current Density = 0.5 X Current Density of the Central Coil (Current = 85 A)

Figures 6 to 10 present the results of the magnetic solution. The wiggler central field in plotted in Figure 11. Figures 12 to 16 present the results of the Lorentz forces acting on the coils. In ANSYS, Lorentz forces are calculated automatically for all current carrying elements. To find the sum of the forces acting on each coil half, we first moved the forces to an element table using the following ANSYS command:

ETABLE, tablename, FMAG, X (or Y)

We then obtained the sum of the forces using the following ANSYS command:

SSUM

These results are summarized in Table 1. The coil dimensions were used to convert the Lorentz forces into the pressure values. To study the influence of the end coil current on Lorentz forces, we repeated these computations with full current in the end coils (rather than half the main coil current). These results are summarized in Table 2.

Table 1: Summary of the Lorentz pressure for the coils of the three-pole wiggler model. I=170 A for the center coil and 85 A for the end coils.

	X-direction Lorentz Pressure (MPa)	*Y-direction Lorentz Pressure (MPa)*
Center Coil	**6.8**	**4.62**
End Coil (half close to the center coil)	**-2.42**	**2.34**
End Coil (half close to the side plate)	**1.05**	**2.64**

Table 2: Summary of the Lorentz pressure for the coils of the three-pole wiggler model. I=170 A for the center and the end coils.

	X-direction Lorentz Pressure (MPa)	*Y-direction Lorentz Pressure (MPa)*
Center Coil	**9.93**	**4.5**
End Coil (half close to the center coil)	**-5.91**	**4.83**
End Coil (half close to the side plate)	**2.81**	**5.77**

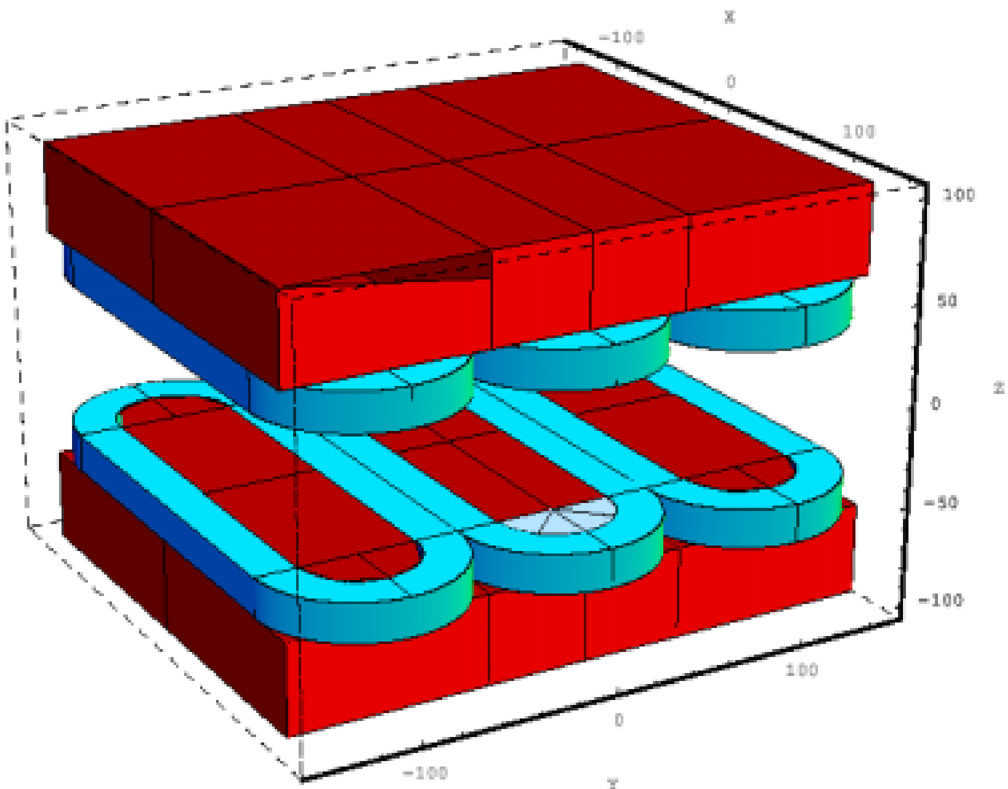

Figure 1: Three-pole wiggler coil and iron arrangement. Coils are shown in blue and the iron in red. Dimensions are in mm. (Source: Gerry Dugan's report [1]).

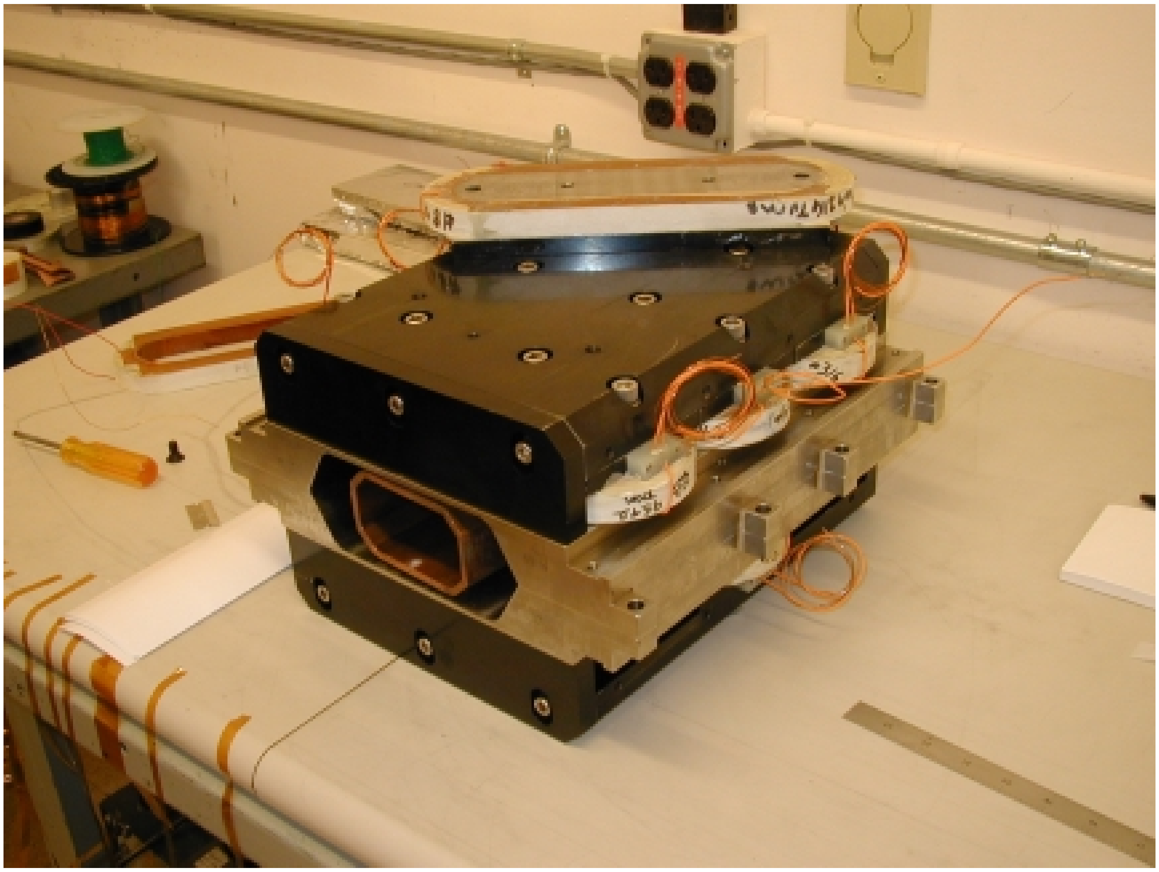

Figure 2: Photograph of the Cornell's three-pole wiggler model.

	T1	0
	H	B
1	166.32	0.5757
2	198.94	0.68
3	240.32	0.7918
4	288.87	0.8949
5	347.36	0.9921
6	417.62	1.0821
7	502.13	1.164
8	603.67	1.2373
9	725.75	1.3021
10	872.17	1.3586
11	1048.8	1.4074
12	1261.3	1.4494
13	1823.1	1.5171
14	2191.6	1.5451
15	3167.2	1.5955
16	4578.9	1.6455
17	6619.2	1.7019
18	9567.6	1.7679
19	11499	1.8045
20	13831	1.8432
21	16624	1.8831
22	19990	1.9236
23	24032	1.9636
24	28893	2.0022
25	34736	2.0384
26	41762	2.0713
27	50209	2.1003
28	60375	2.1251
29	72575	2.1461
30	87257	2.1646
31	1.0491E+05	2.1869
32	1.2612E+05	2.2137
33	1.516E+05	2.2458

Figure 3: BH curve for the iron (1010 steel data taken from Opera) used in the computations. B is in Tesla and H in A/m.

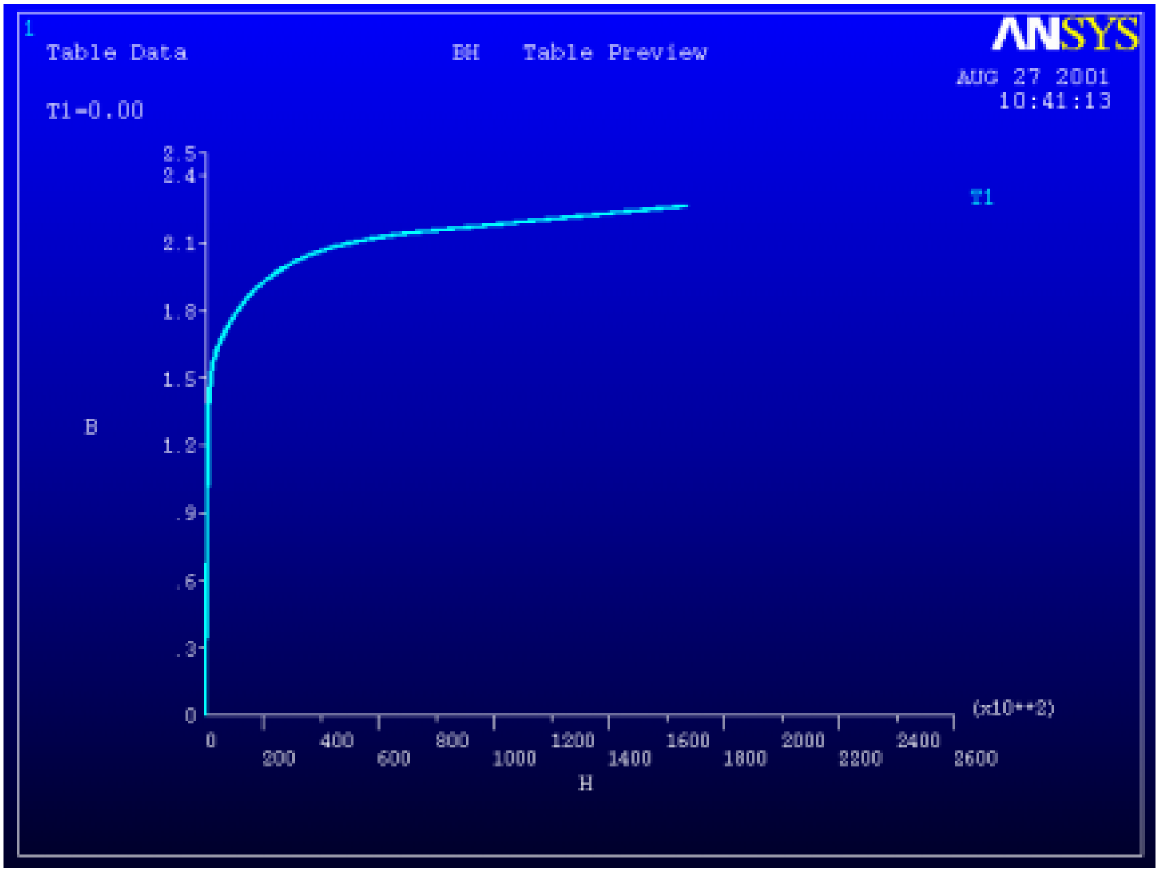

Figure 4: BH plot for the iron used in the computations. The tabulated data is shown Figure 3. B is in Tesla and H in A/m.

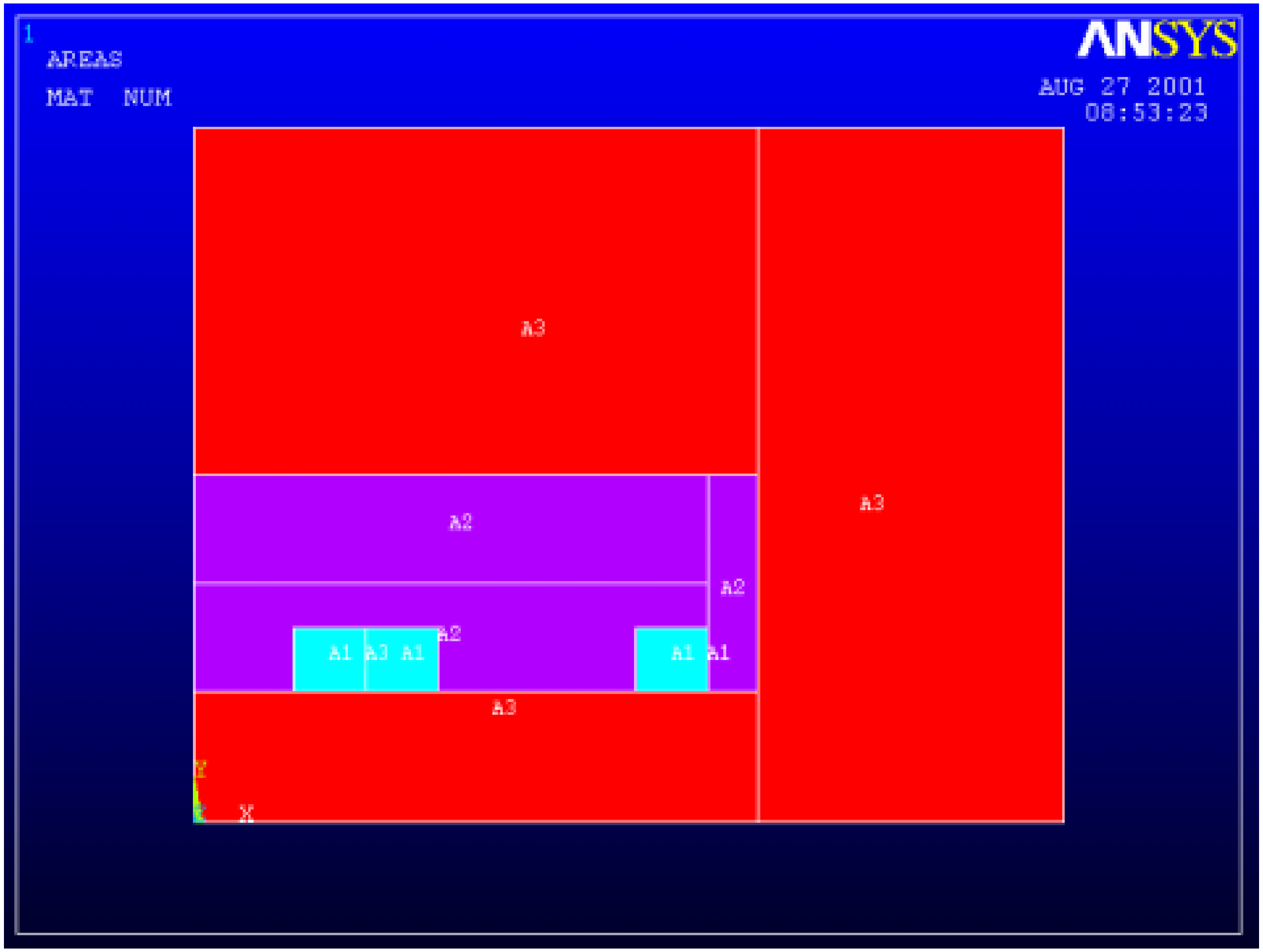

Figure 5: Area representation of the three-pole wiggler model. Due to the symmetry around the YZ plane, only half of the model is considered. The light blue color represents the coils, purple is the iron, and red is air. The leftmost coil half is the center coil, while the other two coil sections on its right represent the end coil. A flux-parallel boundary condition is applied along the Y-axis, while all other sides have a naturally occurring flux-normal boundary condition.

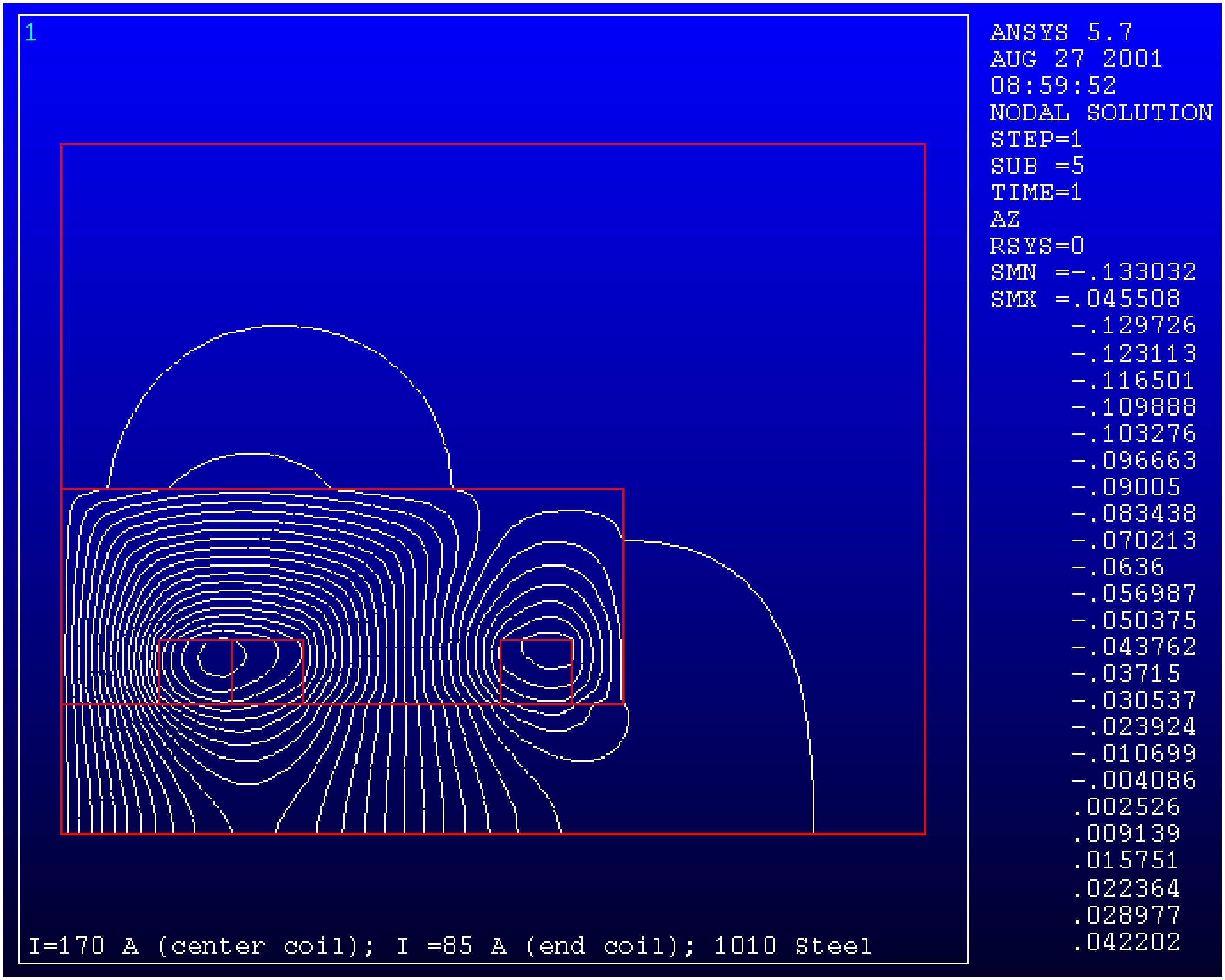

Figure 6: Magnetic flux lines for the wiggler model for an excitation current of 170 A for the center coil and 85 A for the end coils.

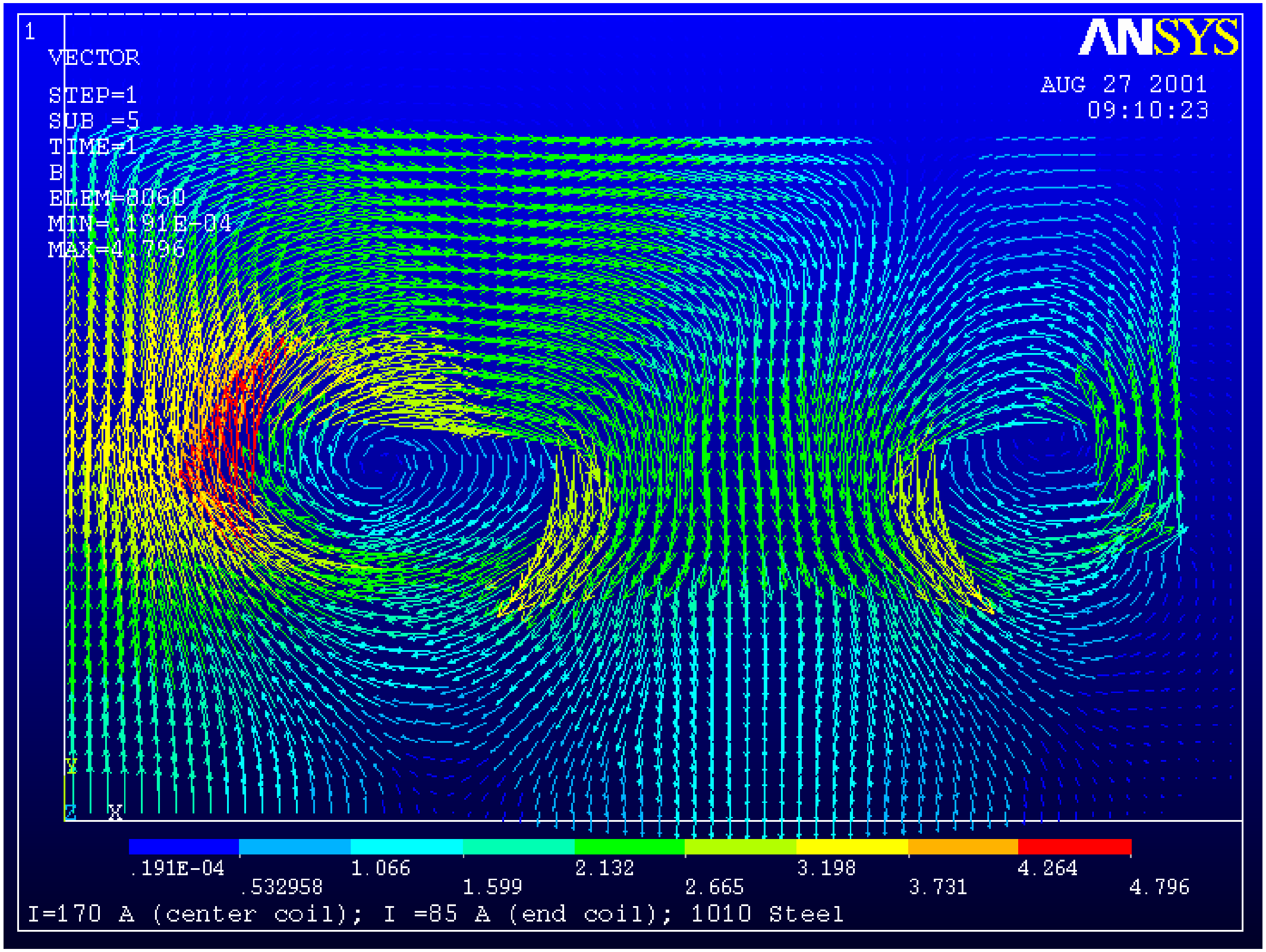

Figure 7: Magnetic flux density vectors (in Tesla) for the three-pole wiggler model.

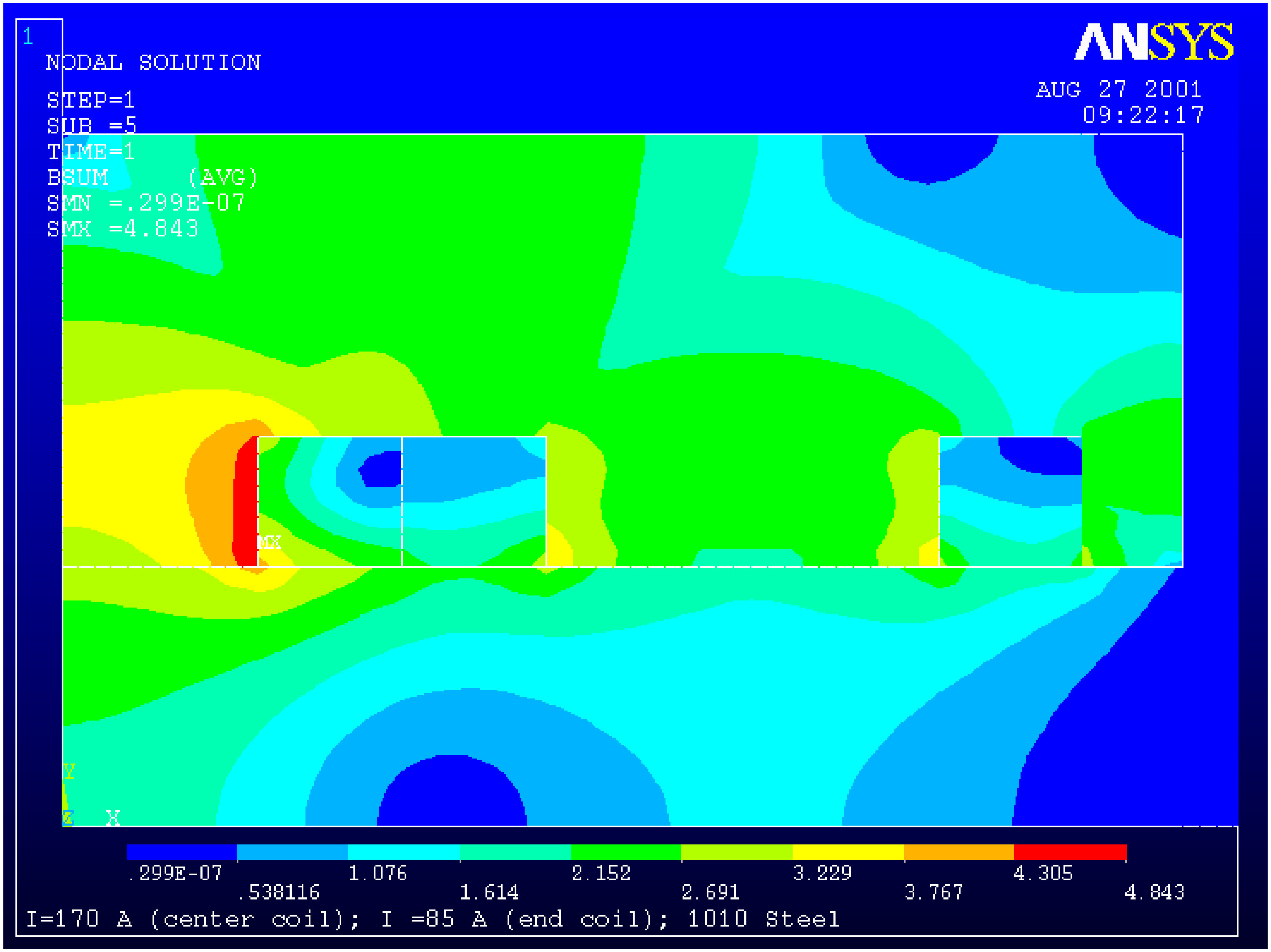

Figure 8: Contour plot of the total magnitude of the magnetic field (in Tesla) for the three-pole wiggler model.

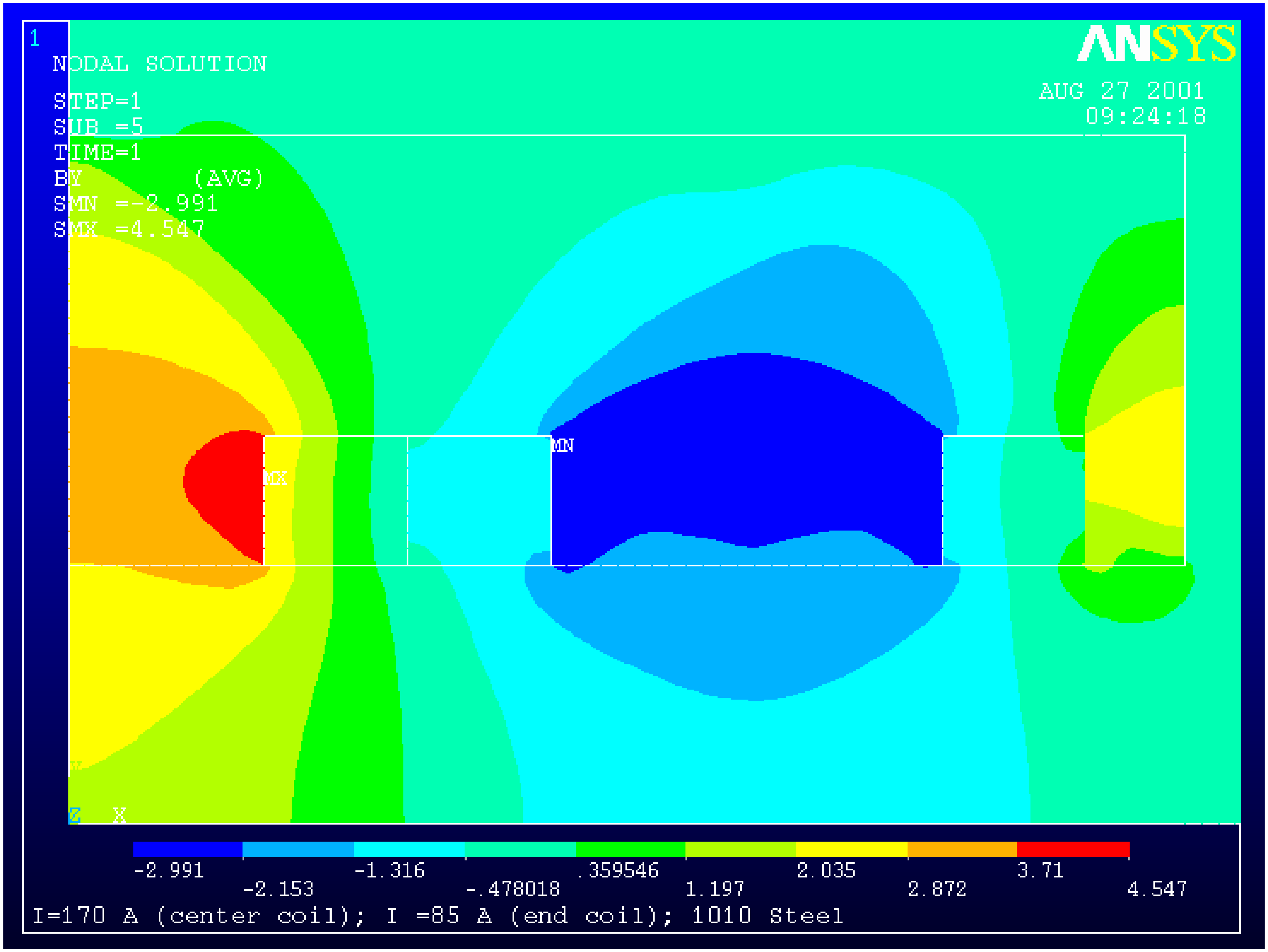

Figure 9: Contour plot of the Y-component of the magnetic field (in Tesla) for the three-pole wiggler model.

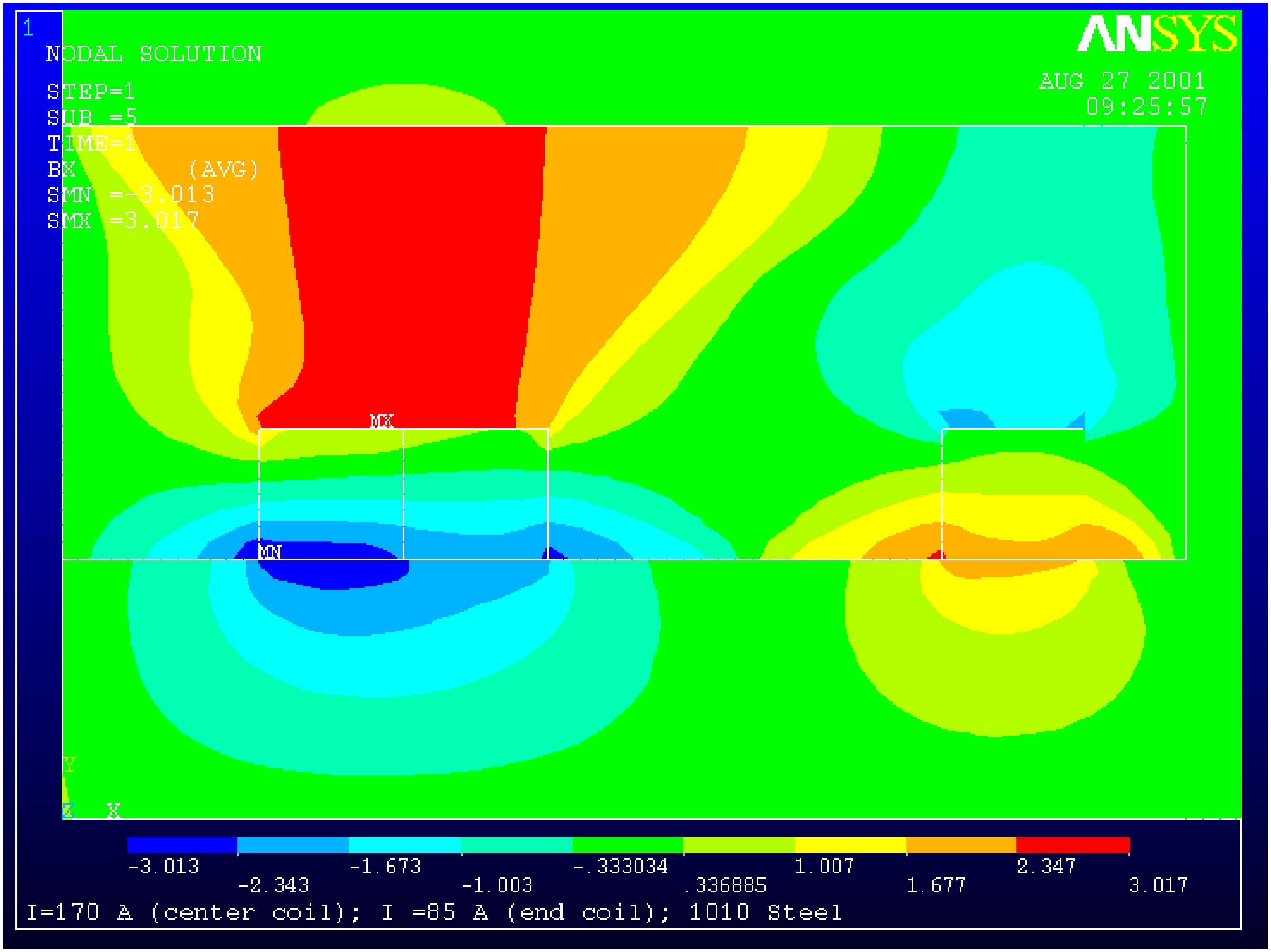

Figure 10: Contour plot of the X-component of the magnetic field (in Tesla) for the three-pole wiggler model.

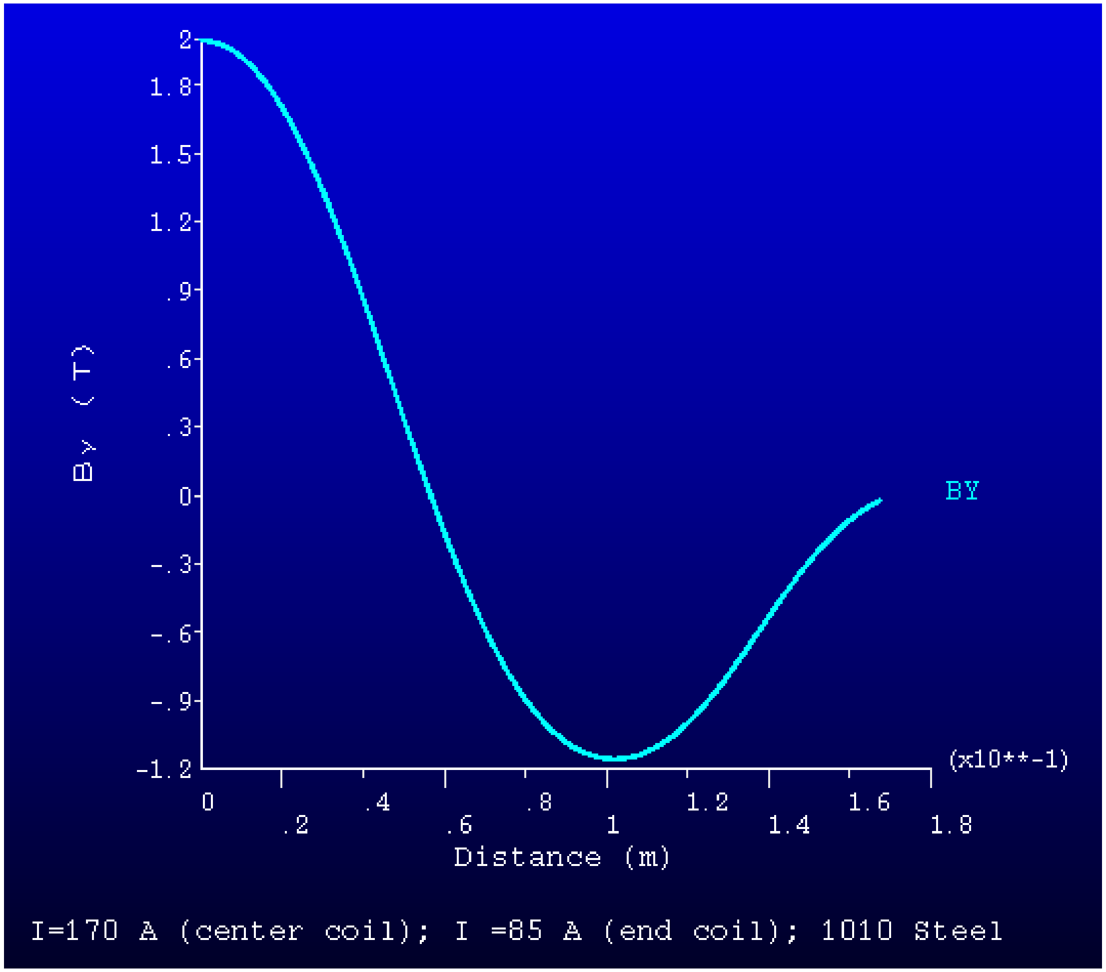

Figure 11: Y-component of the magnetic field (By) along the length of the wiggler model. The field is along the X-axis and for Y=0.

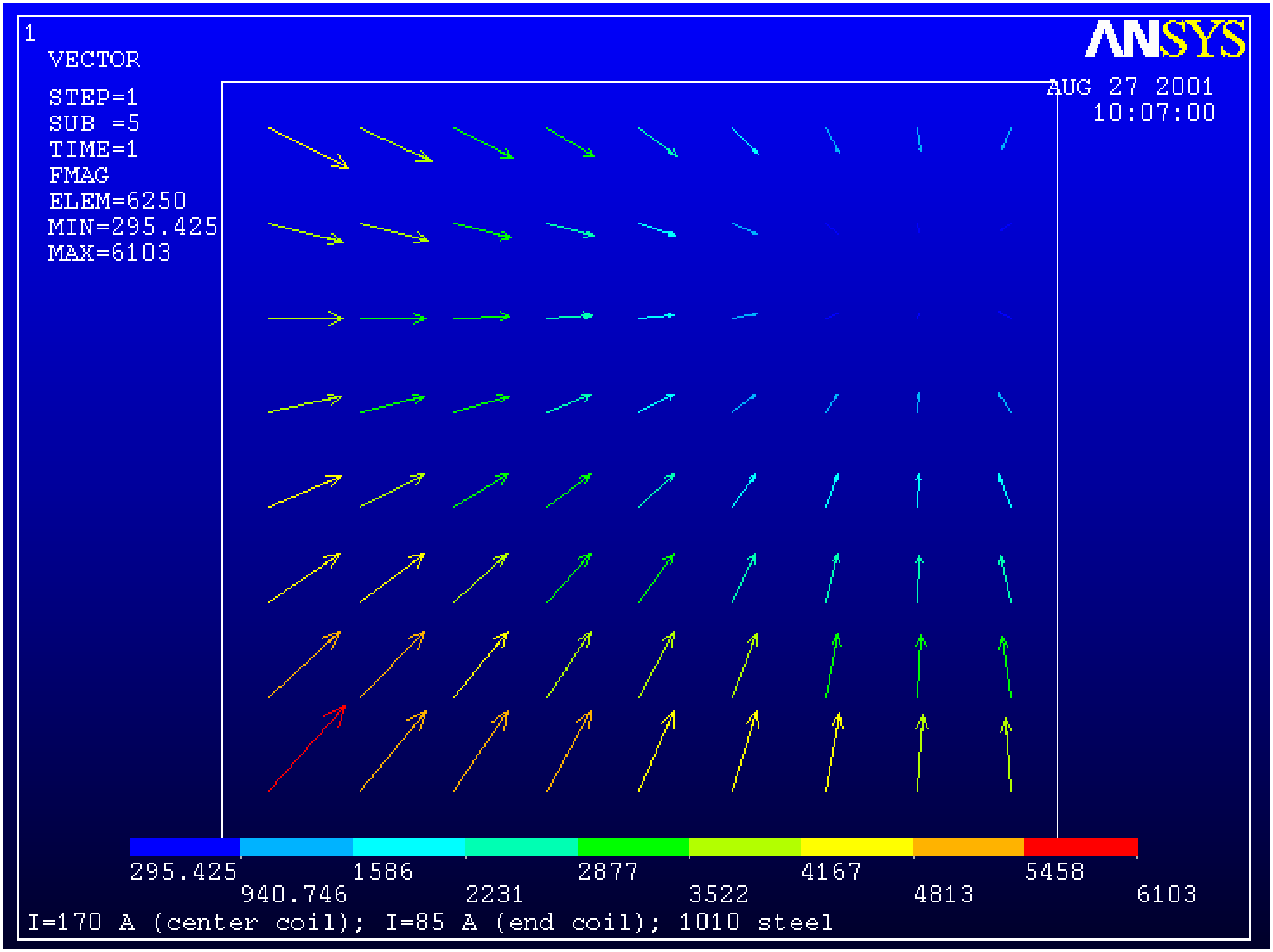

Figure 12: Lorentz force vectors (magnitude in Newton) for the center coil.

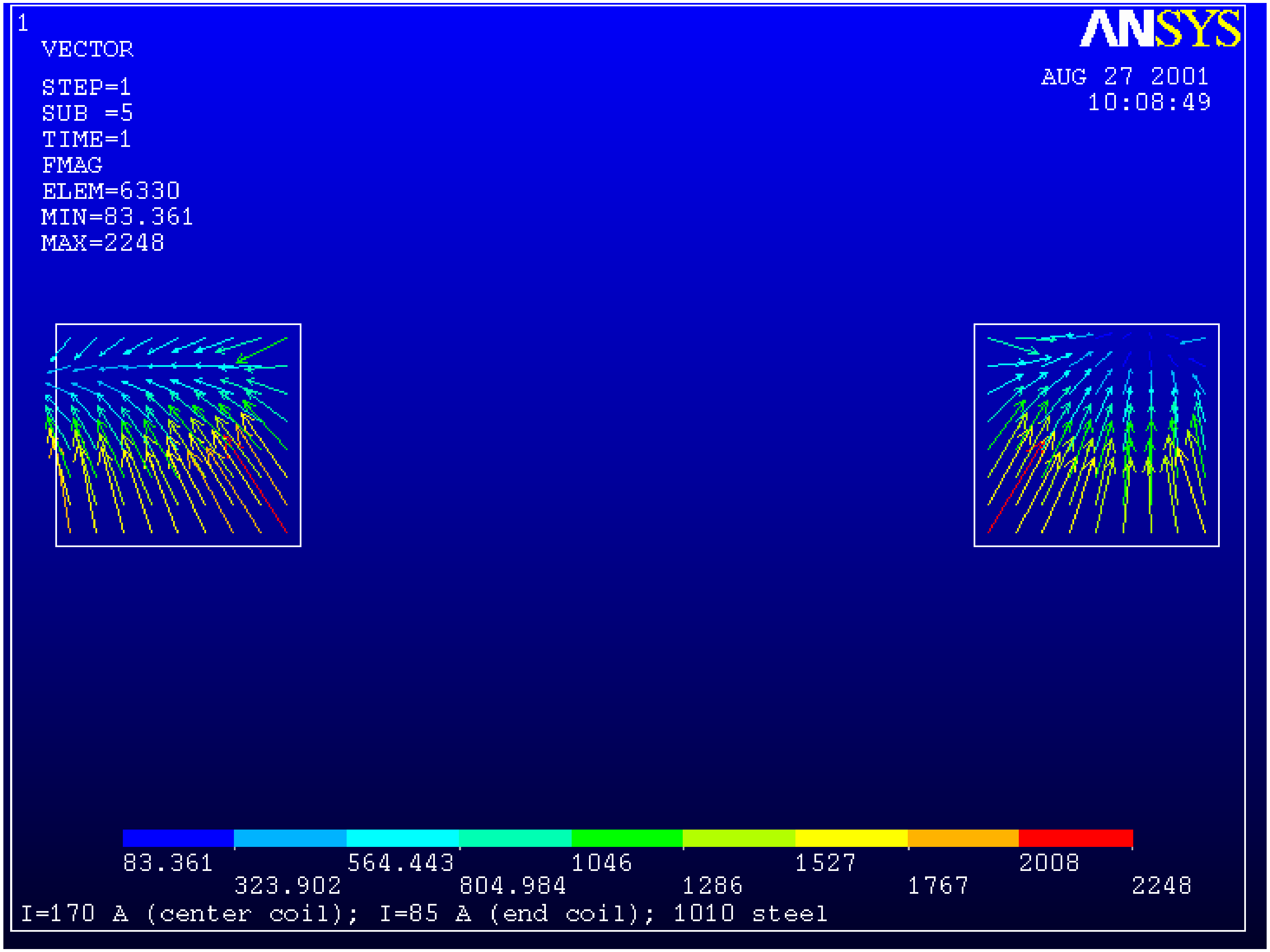

Figure 13: Lorentz force vectors (magnitude in Newton) for the end coil.

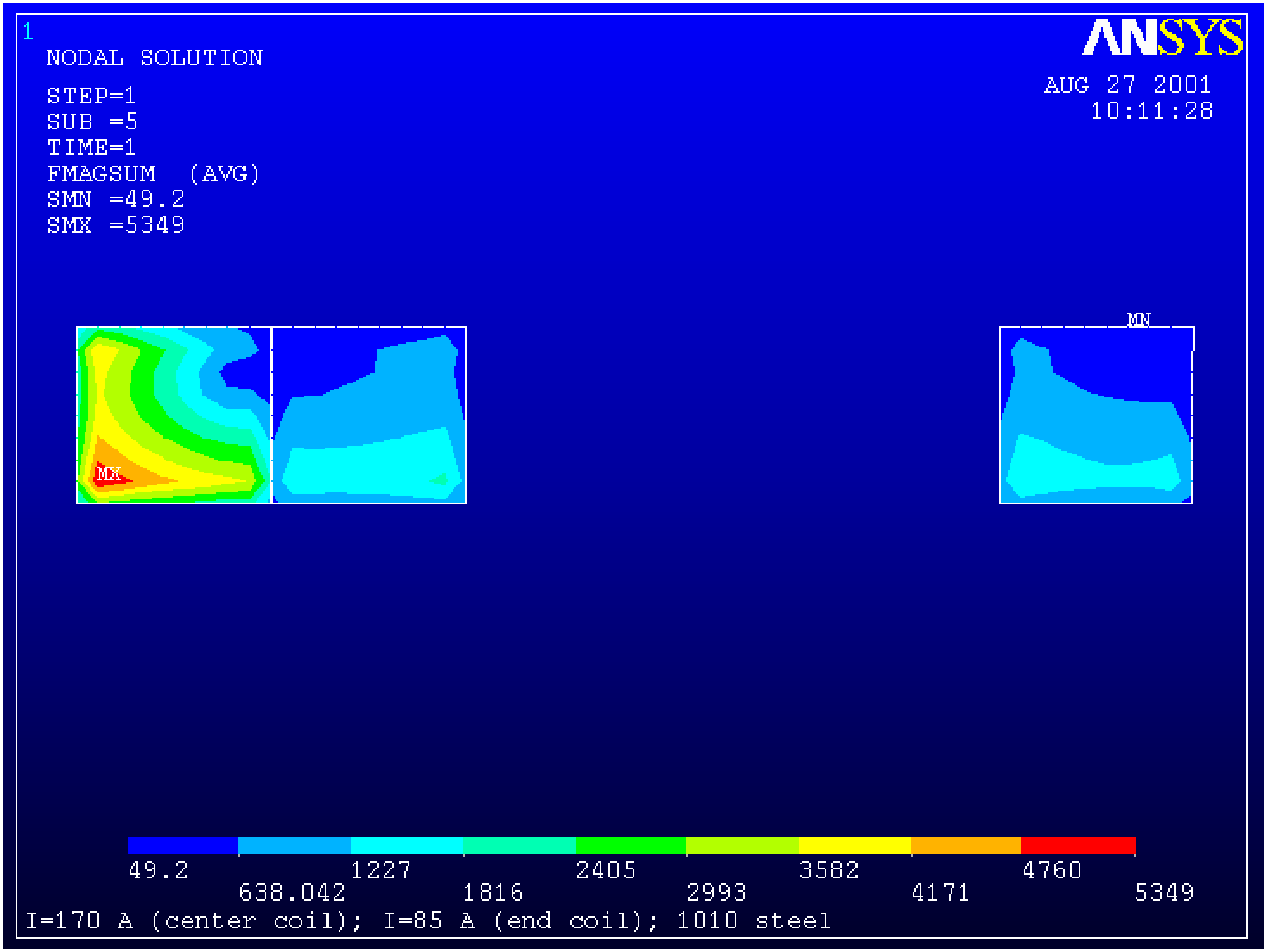

Figure 14: Contour plot of the magnitude of the total Lorentz force (in Newton) for the three-pole wiggler model.

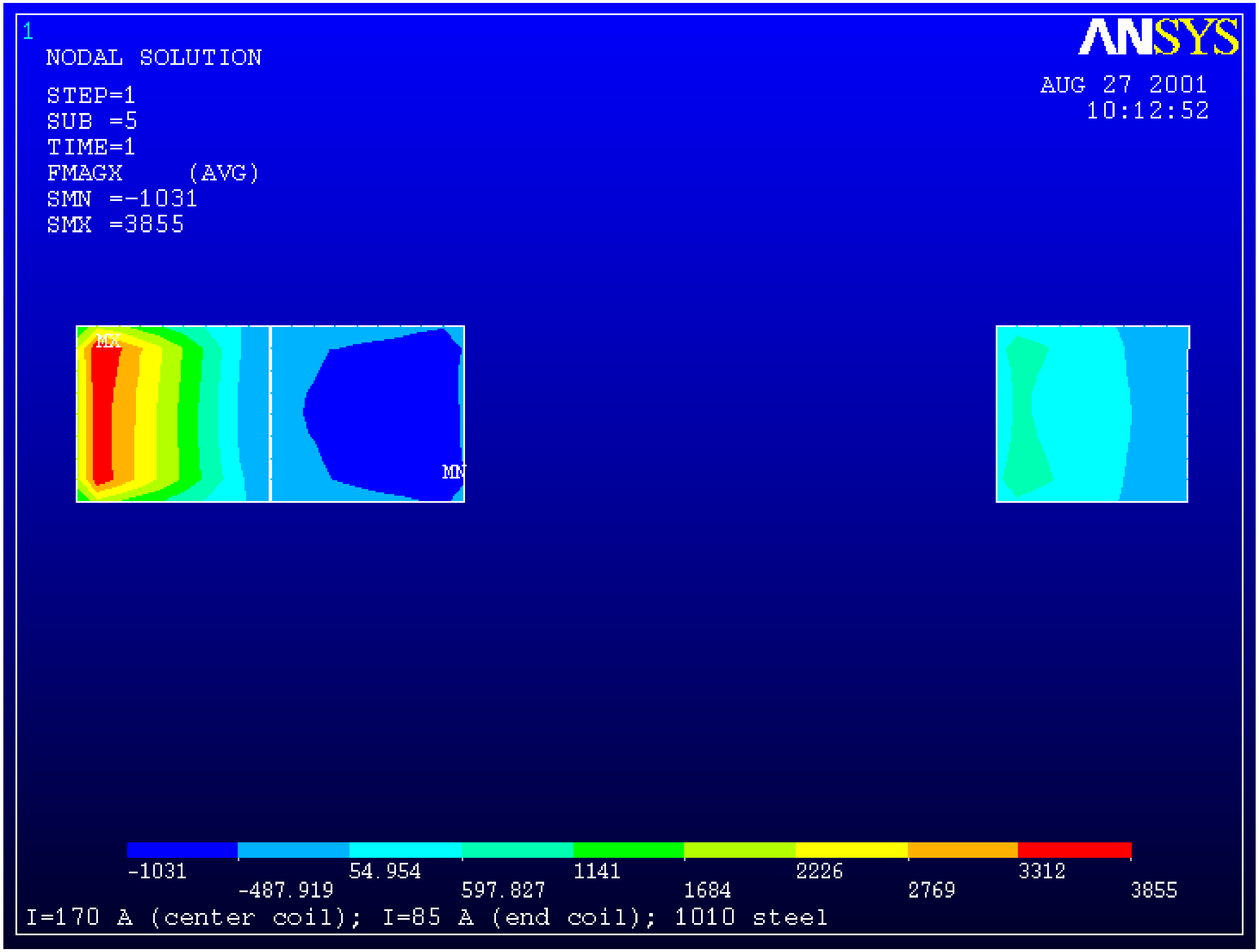

Figure 15: Contour plot of the magnitude of the X-direction Lorentz force (in Newton) for the three-pole wiggler model.

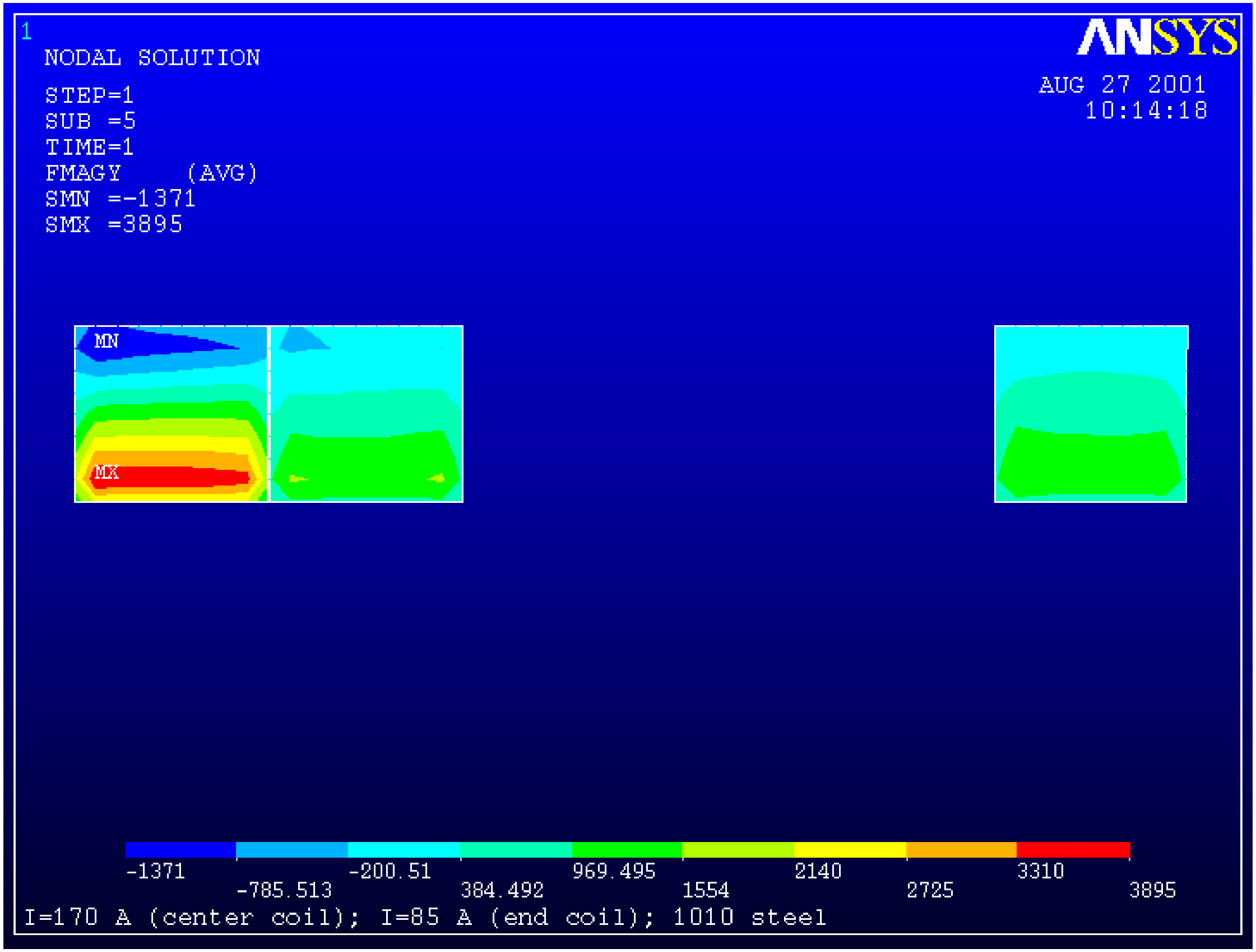

Figure 16: Contour plot of the magnitude of the Y-direction Lorentz force (in Newton) for the three-pole wiggler model.

References

[1] G. Dugan "Two Dimensional ANSYS Model of Three-Pole Wiggler," Internal Report, Laboratory of Nuclear Studies, Cornell University, Ithaca, NY, (2001).